

THE TECHNICAL NEWS BULLETIN OF THE NATIONAL BUREAU OF STANDARDS April 1974

# DIMENSIONS

NBS



**SCIENTIFIC  
FLOODLIGHT  
on  
CORROSION**

# DIMENSIONS

NBS

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**Cover:** Corrosion causes severe economic losses, contributes to disastrous accidents and even to food poisoning. It costs the U.S. an estimated \$15 billion a year—at least \$5 billion of which could be prevented through application of a variety of techniques, some of them developed by NBS scientists. See article on page 84.



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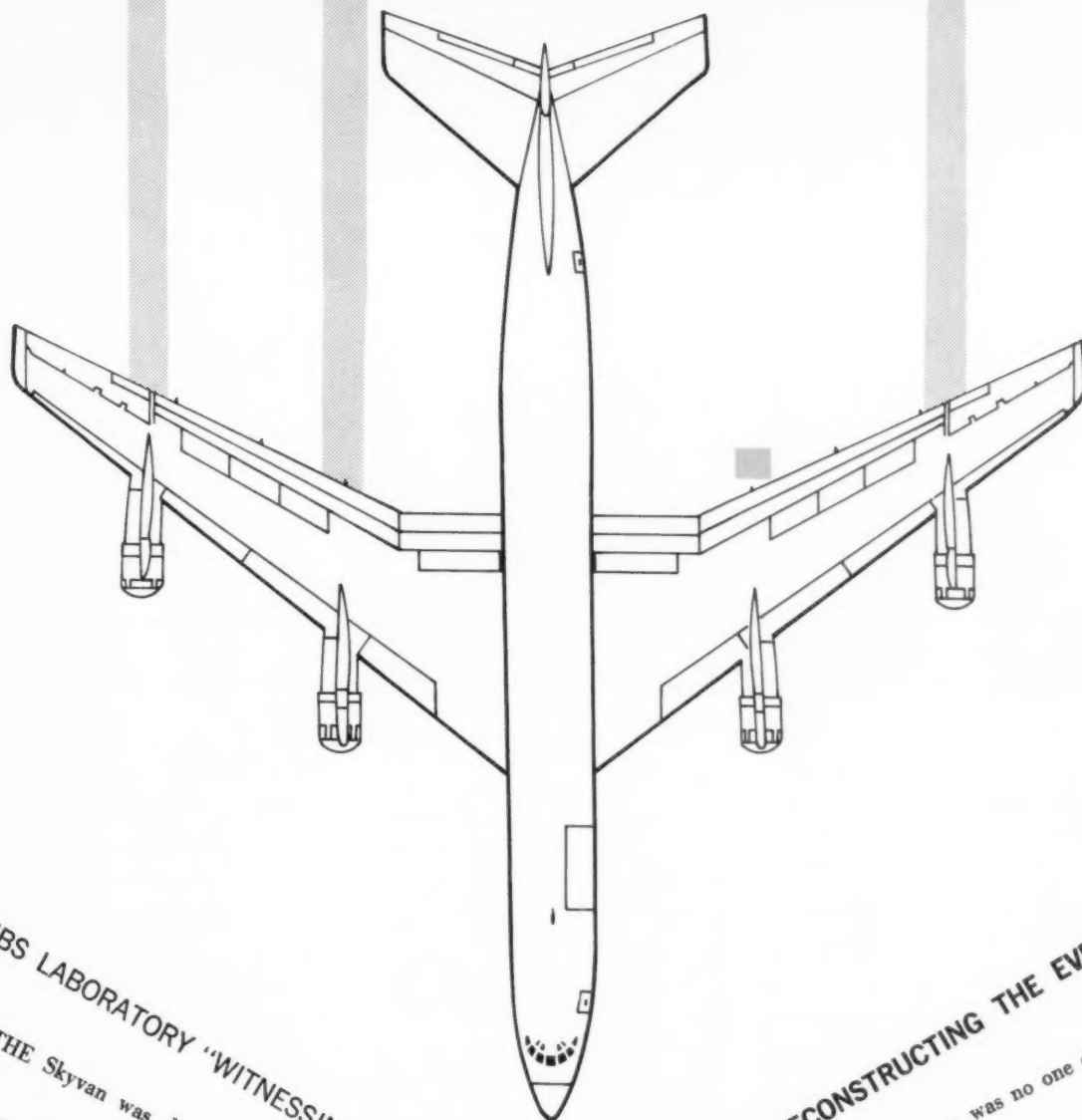
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**NBS LABORATORY "WITNESSING"**

**AIRCRAFT FAILURE:**

**RECONSTRUCTING THE EVENT**

THE Skyvan was demolished but did not burn. Both crewmen were killed in the crash. There was no one else on board—only cargo. Who could say what had happened? Metallurgist T. Robert Shives of the National Bureau of Standards wasn't there. He didn't see the craft nose down, roll to the left, strike the water at Roaches Run, cartwheel onto its right wingtip and sink 3.6 to 4.5 meters (12 to 15 feet). Many witnesses did see it from the

ground or the air around Washington National Airport, but their observations were limited. "It was so hazy," recalled a corporation plane pilot who saw the Skyvan go down, "that I could not be sure of the aircraft's color. I think it was blue and white." Nevertheless, he and other witnesses managed to provide investigating authorities with useful descriptions of the Skyvan's erratic behavior up until the moment when it "did a 'split S' . . . disappeared behind a clump of trees . . . (and sent up) a large splash of water . . . above and between trees in the vicinity of the Potomac River or Basin near the 14th Street Bridge."

Technical reports—one of them by Shives—would come weeks or months later, reflecting none *turn page*



#### AIRCRAFT *continued*

of the immediacy and drama of the original event but making the best of whatever hard evidence or fragmentary clues were available. The crash or near-crash that begins with a bang or a whimper, a "loud explosion and terrific vibration," or perhaps only a "dull pop noise in the engine compartment," often approaches its moment of truth only after subsequent cool scrutiny by failure analysts such as Shives dealing minutely with such things as fracture surfaces, microstructures, and deformation characteristics in a modern, well-equipped metallurgical laboratory far from the accident.

Thus it was with the Skyvan failure. Nonwitness Shives, of course, could contribute nothing by way of general description of the accident. Back in his laboratory, however, he could attain a certain clarity not available to eyewitnesses even on the sunniest day. So, as on numerous earlier occasions, the National Transportation Safety Board's Bureau of Aviation Safety sent some key parts from the wreck to this expert NBS staffer of 15 years' standing who has

been peering through his instruments at such evidence increasingly over the years.

When Shives received the parts—two undamaged sidewall seat-retaining ring assemblies, attached to small sections of fuselage—he focused narrowly on the technical question before him, taking no official notice of the "hot cargo" headline aspect of the crash (concerning two missing—and soon recovered—radioactive isotope containers).

#### Breaking Loads

Shives' assigned task in this case was comparatively simple. He was asked to determine the breaking loads of the rings by pulling one in the direction of the assembly's long axis and the other at 45 degrees from the long axis. For testing, each retaining ring assembly was removed from the fuselage section and clamped in a tensile machine by specially designed jigs. Pulling the ring assemblies in the machine at a speed of .51 millimeter (0.02 inch) per minute, Shives found that in each case the aluminum strip looped around the rings failed—assembly number 1 (stress along long axis) at a breaking load of 5852

newtons (1330) pounds, assembly number 2 (stress 45 degrees to long axis) at 1760 newtons (400 pounds). Other parts were tested to failure at Safety Board headquarters and the Skyvan's engines were examined at a Phoenix, Ariz., manufacturing plant.

#### Probable Cause

Putting together the eyewitness accounts and laboratory investigation results, the Board found that the accident was probably caused by loss of effective elevator control due to the forward shift of improperly secured cargo when the aircraft was placed in a steep nosedown attitude during a landing approach in reduced visibility conditions. This finding prompted several actions:

- a National Transportation Safety Board recommendation that the Federal Aviation Agency alert all taxi cargo operators to the importance of following existing regulations on stowing and securing cargo, with particular attention to manufacturers' specifications for the aircraft involved.
- two manufacturer's bulletins on "Flying Controls" and "Equipment



and Furnishings," designed to prevent a repetition of the Skyvan crash. The first introduced a redesigned fork-end fitting in the elevator control circuit and the second related to equipment and furnishings to fit the guards at the rear of the two pilots' seats.

Cases vary widely and conclusions may range from quite positive to tentative. One of the most unusual incidents of recent years was the death plunge of an Australian birdman performing before a Memorial Day crowd of thousands at Dulles Airport's 1972 Transpo exposition. Riding his large delta-shaped sky-kite 150 meters (about 490 feet) into the air behind a speeding tow car, the ill-fated performer was in a steep climb when a gusting wind apparently entangled him in the kite and brought him "straight to the ground—just like a stone." All Shives had to work with in this case was a section of the kite's wire cable that turned out to be too short for testing to failure by normal techniques. He therefore contrived an alternative approach, tested the cable and arrived at a calculated breaking load and ultimate tensile strength based upon it.

#### Adaptable Investigators

Kite or 'copter, passenger liner or cargo carrier, air taxi or blimp—Shives and his fellow NBS failure investigators take the cases as they come and adapt themselves to circumstances. Not long ago, for example, Shives and Leonard C. Smith, a colleague in the Mechanical Properties Section, had to work with two partly disassembled gyroscopes from an aircraft whose wreckage had lain exposed to rain and the marine atmosphere at Indiantown, Fla., for a week. Shives and Smith, considering among other things the question of how much corrosion of certain components had occurred before the crash and how much after, drew upon the talents of Bill Gerhold of the Corrosion Section in dealing with the problem.



*Bob Shives looks an aircraft part over before putting it under the microscope.*

Reconstructing the failure itself often requires in-depth analysis that reaches back to the manufacturing process if not even earlier to the drawing-board stages of design. In one case, for example, failure of an exhaust valve rocker box from an engine involved in a crash at Lino Lakes, Minn., was linked to fatigue cracks, with evidence suggesting improper heat treatment of the part at the time of manufacture. In this analysis Shives and Smith were aided by the scanning electron microscopy of Dave Ballard and chemical analyses by the NBS Spectrochemical Section.

A complex "whatdunit" was presented in the case of a helicopter that cut off its own tail boom when the main rotor blades flexed downward during an emergency landing on a house driveway in Piscataway, N.J. NBS, examining a fractured free-wheeling transmission gear submitted by the Bureau of Aviation Safety, arrived at 11 technical findings. One concerned a stress-raising crack that followed a tool mark in the root between two gear teeth—a crack that must have originated during final

machining operations when the 'copter was being manufactured. Other technical findings concerned three fractures, fatigue cracks between inside gear teeth opposite outside points of wear, a corrosion check with negative results, the presence of brittle iron oxides, globular inclusions and related evidence. The NBS report was written by Shives, aided by the metallography of Smith and Don Harne of the Mechanical Properties Section and the microscopy of Charlie Brady and Ballard.

The quality of a weld was a central issue in the investigation of an Elwood, Ind., aircraft crash that killed the lone pilot. The weld in question had held a pin and gear to a control wheel adapter, and the pin had pulled out in the crash. NBS was called upon to examine the failed adapter, control column and control wheel. At the same time, the Bureau of Aviation Safety submitted a new adapter for testing in tension to determine the load necessary to cause failure. Smith and Shives examined the failed adapter by eye and under the microscope while Don Robinson of the Engineering Mechanics Section calculated the force necessary to cause failure in the fractured adapter.

#### More Than Mechanical

Clearly, the investigative problems presented to NBS failure analysts are mechanical in nature—but the fruit of effective work in this area is more reliable protection of human life and property as a result of safety, maintenance and design lessons learned from mishaps and catastrophes. More than 60 years ago, Congress and the Interstate Commerce Commission drew upon NBS expertise to help solve the mystery presented by a rash of railroad track and wheel failures—traced to flaws in the metal attributable to faulty manufacturing processes that were subsequently improved. For the country's air carriers and passengers today, NBS continues to make important contributions. □

## JILA Honors Copernicus



# Man and Cosmos LECTURE SERIES

A world-wide quinquennial commemoration last year honored the birth of Nicholas Copernicus, famed Polish astronomer who revolutionized astronomy and physics with his theory that the sun, not the earth, is the center of our planetary system.

As part of this observance, the Joint Institute for Laboratory Astrophysics (JILA), operated by the National Bureau of Standards and the University of Colorado at Boulder, sponsored a series of lectures on "Man and Cosmos." The lectures were part of an effort to help science tell its story to a public which, although it lives in a culture dominated by science and technology, frequently doesn't understand their significance to everyday social and economic concerns.

Dr. David G. Hummer, NBS staff member and chairman of JILA, and Professor Richard McCray of JILA arranged for three of the world's most eminent astronomers to deliver free public lectures at the University of Colorado. Over 2,000 persons attended each of these guest lectures by: Owen Gingerich, Professor of Astronomy and History of Science, Harvard University and Smithsonian Astrophysical Observatory; Carl Sagan, Professor of Astronomy and Space Sciences, Cornell University and Martin Rees, Plumian Professor of Astronomy, University of Cambridge, England.

Professor Gingerich, a foremost authority on Copernican history, talked about the "Copernican Revolution" and recalled that Copernicus was born in Torun, Poland, in 1473. His father died when he was 10, but a maternal Uncle, Lucas Watzenrode, a successful ecclesiastical politician, provided for young Copernicus' education. At the University of Krakow, the most learned astronomers of the time tutored him in the works of Sacrobosco, Regiomontanus, Ptolemy and Euclid. Later, Copernicus studied Canon Law at Bologna, Italy; medicine at Padua, Italy; and received a doctorate in Canon Law at Ferrara,

Italy. Professionally he was a lawyer, but his lifelong primary interest was in astronomy and cosmology.

In 1503, Uncle Lucas (who was by then Bishop of Varmia), through an act of "benevolent nepotism," arranged for Copernicus to be appointed one of 16 Varmian Canons, the highest level of administration under the Bishop. Thus, at the age of 30, Copernicus was financially secure to pursue his astronomical sideline.

### When Did It Begin?

There is nothing in his history, according to Professor Gingerich, that reveals a reason for Copernicus' conclusion that the sun was the center of our planetary system. "We do not know," said Gingerich, "when Copernicus began to meditate on the mobility of the Earth." He first announced his assumptions in a 6-page, anonymous tract called *Commentariolus*, written before 1514. His historical work, *De Revolutionibus*, is a 404-page book fully expounding his thesis. The title, which translates, "Concerning the Revolutions," is an abridgement of Copernicus' original title, *De Revolutionibus Origium Coelestium*, "Concerning the Revolutions of the Heavenly Spheres." It came to be published only at the urging of a young admirer, Georg Joachim Rheticus, Professor of Astronomy at Wittenburg, Germany. The publication date is not definitely known, but was probably March or April 1543. More than 200 first editions exist, as does the original Copernican manuscript.

Copernicus perhaps saw a copy of the finished book, but did not live to enjoy the accolades, nor suffer the derision, generated by his revolutionary theory. He suffered a stroke and died that year at the age of 70.

In the following years, the validity of his hypothesis became apparent to increasing numbers of astronomers and physicists, and men like Galileo and Newton built a new science upon the foundation of its truth. The Copernican Theory became the basis for modern science which made possible

a chariot to carry man to the moon.

More than 2,500 persons were on hand as Professor Sagan discussed "The Cosmic Connection: The Search for Extraterrestrial Life." With great clarity, Professor Sagan explained why he believes there are probably roughly one million "technical civilizations" in our Galaxy, the Milky Way. He defined a technical civilization as one which is capable of sending radio communications into space. He arrived at this estimate by plugging a complexity of variables and educated guesses into a standard formula to make a "most likely case" for his hypothesis. He says our universe should be "littered with building blocks of life," in the presence of four elements responsible for life on earth: oxygen, hydrogen, nitrogen and carbon.

### To Whom It May Concern

Sagan's discipline, exobiology, deals with the possibility of extraterrestrial life and the means for its detection. He has written more than 150 scientific articles and is the author or editor of more than 11 books on the subject. It was Sagan who was responsible for placing aboard the Pioneer 10 spacecraft the first man-made object to leave the solar system, a message intended for possible extraterrestrial civilizations. On the shell of the spacecraft, as it left the confines of the solar system last December, was a gold plaque carrying symbolic data locating Earth and specifying our epoch through the use of astronomical phenomena. On the plaque also are sketches of a nude woman and man with arms upraised in a "universal gesture of goodwill."

Martin Rees, the Cambridge professor, spoke on "The Origin and Fate of the Universe." He said that the universe seems to be the product of an endless dynamic process. Galaxies, the building blocks of the universe, appear to form, mature and die. Within the galaxies, stars like our sun, assemble from elements within the universe, burn furiously for bil-

lions of years and, upon exhausting their energy, either become cold dense "cinders" or explode to become supernova, neutron stars, pulsars and eventually black holes with gravity so strong that not even light can escape them.

Far out in space are the quasars, phenomenal masses of cosmic materials loosely combined, but throbbing with energy of microwaves and light. Though little understood, they are believed to be embryonic galaxies, which, in the vast timetable of eternity, are being born. They are likely to be, in Rees' opinion, a recombination of cosmic materials which have been elements of a galaxy before—perhaps several times. This idea suggests that our Earth, and all upon it, may be recycled cosmic refuse.

Those who heard Rees' lecture could only conclude that neither the origin nor the fate of the universe is definitely predictable, as many of the phenomena involved, Rees readily admits, are still beyond human knowledge and understanding. Astronomers' educated guesses range from continued expansion of the universe until it suffers a "heat death" (actually a lack-of-heat death) to the opposite, that is, a shrinking and recombination of cosmic materials.

### Another View

Other scientists believe that neither of those alternatives are the fate of the universe. Instead, they contend, the universe is much as it always has been, with birth and death of its components recurring forever.

Exactly 14 days after Professor Rees' lecture, the Earth, true to Copernican prognosis, completed another yearly orbit around the sun and ended the quincentenary anniversary of the famed Polish scientist's birth. The year 1973 joined the multibillions of years before it and became a part of the past. Meanwhile, the revolution of the heavenly spheres continues through time and space, toward a fate uncertain in the understanding of men. □

# POLICE HELMETS: HOW SAFE?



*The suspension webbing in this riot helmet provides effective protection only against a blow to the top of the head. If struck on the side, front or back of the head, its wearer could be seriously injured.*

When a policeman is trying to control a riot, confronting a sniper or just patrolling the streets, he should not have to worry about the effectiveness of his protective equipment. But tests at the National Bureau of Standards indicate that many models of police helmets readily available on the market might fail to prevent serious brain injury to the wearer during the course of hazardous duty.

The work provides the technical base for standards for safety for both police forces and manufacturers. It was done at the Bureau by the Measurement Engineering Division and the Law Enforcement Standards Laboratories under the auspices of the National Institute of Law Enforcement and Criminal Justice, Department of Justice.

Only the largest police forces, with sufficient technical and financial resources, are capable of testing protective equipment to determine their own guidelines. Most have to rely on the promises and explanations of the manufacturers' salesmen. Adequate safety performance standards for helmets and face shields are clearly needed for the protection of law enforcement officers in the line of duty.

## Brain Damage

NBS project leader Nicholas J. Calvano, a chemical engineer, reports that when a projectile, such as a brick or a bullet, strikes a person's head—even one covered with a helmet—the force causes the brain to begin to move with a tremendous acceleration. If the head is jarred by such a force causing acceleration greater than 400 times that due to gravity (400 g's), brain damage can be expected. This dividing line between safety and danger is only an estimate. It varies from person to person and depends upon which part of the head is hit.

The NBS' tests were conducted on three types of helmets: riot, ballistic (bulletproof) and crash. A low resonance (non-ringing), magnesium form, shaped like the upper portion of the



human head, was equipped at its center with an accelerometer to register g-forces on an oscilloscope. The form was fitted with the headgear to determine "impact attenuation," or the amount of acceleration the form's "brain" must endure from the simulated use. Ballistic helmets were also tested for bullet penetration.

### Riot Helmets Worst

Of the three helmet types, the riot headpieces, which are made of either glass-reinforced plastic or polycarbonate, performed the worst. NBS researchers dropped the helmeted form onto a hemispherical steel anvil from a height of 2 meters (6.5 ft) to represent the blow of a well-thrown brick. The form was aimed to strike the anvil on the helmet's side, front, top and back. Only two of 10 models manufactured gave reasonably adequate protection.

Four of the riot helmets tested were marginally effective, providing protection only to the top of the head. One of these afforded such an uneven defense that if the helmet had been struck on the top, the brain would have sustained only 100 g's; but if hit on the side, the force would have been 14 times as great. This type is modeled after the hardhat designed to be worn on a construction site. There, a person is likely to be hit by a falling object only from directly above. Although the suspension webbing in this armor can absorb this kind of impact well, any lateral force is virtually unaffected by the helmet. The remaining four helmets tested gave almost no protection.

### Partial Protection

The ballistic helmets also showed uneven performance. Ideally, bullet-proof headgear should live up to its name. But to do so would make the helmets too heavy to be practical. More realistically, to provide proper protection in a gun battle, such a helmet should render non-lethal a bullet fired by any firearm the police might normally encounter. Two of the

*If project leader Nicholas Calcano had been wearing either helmet he's holding in his hands during the ballistic testing, he might have received serious brain damage from some of the more penetrating bullets.*



three products available to police did, one more easily than the other.

Looking like a WW II German helmet and made of glass-reinforced plastic, one model kept the impact acceleration at or below 400 g's in two of three cases against two of the most penetrating bullets tested—the .357 and the .41 magnum. The two least powerful (revolver fired .22 Long Rifle and 9 mm bullets) and the two moderately penetrating rounds (rifle-fired .22 Long Rifle and .38 Special) did not penetrate or present any dangerous acceleration to this helmet.

Quite unlike this armor is a ballistic headpiece consisting of a modified plastic crash helmet that does not extend protection to the back of the neck or to the ears as does the one just mentioned. This second model is adapted by the addition of a thick, multilayered nylon cap. As advertised, it is effective only against small-caliber ammunition fired from a revolver; not against the same bullet shot from a rifle. This helmet, which weighs only about half as much as the more protective one, could not stop even the least penetrating bullets.

The third model of ballistic helmet is similar in design and composition to the first helmet described but with

slightly less protection to the back of the neck. It prevented penetration by all but a few of the most powerful rounds. However, it was unable to keep the acceleration under the brain damage borderline against any of these powerful shots.

### Crash Helmets

Crash helmets, protection any motorcyclist might purchase, are also made of polycarbonate or glass-reinforced plastic. They were tested by a drop from the same height as were the riot models, but onto a flat anvil which simulated a paved surface. Unlike the ballistic and riot headgear, a severe shock to this equipment can partially destroy its effectiveness without any noticeable change to the outside.

In this case, some of the plastic foam padding was compacted when struck, causing it to lose its shock-absorbing feature at that point. A second drop from 1.75 meters (5.7 ft) was added to the test with the helmet aimed to strike on the same spot as in the first drop.

Eight of 13 crash helmets tested survived both drop tests to the top, side, back and front. Three more proved effective against all but one drop. Only two tested so poorly as to fail three drops each. □

# HIGHLIGHTS

## Energy Conservation Kit

NBS is developing a guidebook to help managers of small and intermediate-sized industries to achieve energy savings. The guide contains tips on setting up and operating an energy management program and offers technical suggestions on increasing efficiency of energy use in areas such as plant operations, process steam and waste heat recovery. Much of this information is based on the experience of large firms that have had success in their own energy conservation programs. NBS is coordinating this effort with the Office of Energy Programs in the Department of Commerce, which will assist in making this information available to industry.

## Lead Paint Detection

The Department of Housing and Urban Development is inviting research and development firms to participate in developing quick, reliable, simple and nondestructive means for detecting and measuring lead in the painted surfaces of old dwellings. NBS will monitor the resulting contracts and will evaluate the efficiency of prototype devices and systems for lead detection and measurement.

## School Paints and Inks

A recommended voluntary standard for paints and inks for art education in schools is now being circulated by NBS to producers, distributors and users of these products for review. The standard covers finger paints, liquid and powder tempera paints, semi-moist water colors and block printing inks. It includes require-

ments for the material, shelf life, toxicity, working qualities and packaging of the paints and inks.

Copies of the recommended standard are available without charge from the Office of Engineering Standards Services, NBS, Washington, D.C. 20234.

## Ultraviolet Mercury Lasers

NBS has found that a largely ignored fluorescence band in mercury may provide a significant energy release which may be useful in ultraviolet mercury lasers. Measurements of the 335-nm and 485-nm bands in superheated mercury vapor showed an exponential increase in the intensity of the 335-nm band while the 485-nm band decreased. As a result of this finding, the dissociation laser group at the Air Force Weapons Laboratory will attempt to achieve laser action at this wavelength.

## Silicon Resistivity SRM

A set of two boron-doped silicon wafers, Standard Reference Material 1520, certified for values of nominal resistivity is now available from NBS at a cost of \$427. The standards are used to calibrate four-probe resistivity apparatus. The measurement of resistivity is the most important materials acceptance criterion used by silicon producers, transistor manufacturers and users.

For additional information, write or call the Office of Standard Reference Materials, NBS, Washington, D.C. 20234. Telephone 301/921-2045.

## Federal Data Elements

Secretary of Commerce Dent has ap-

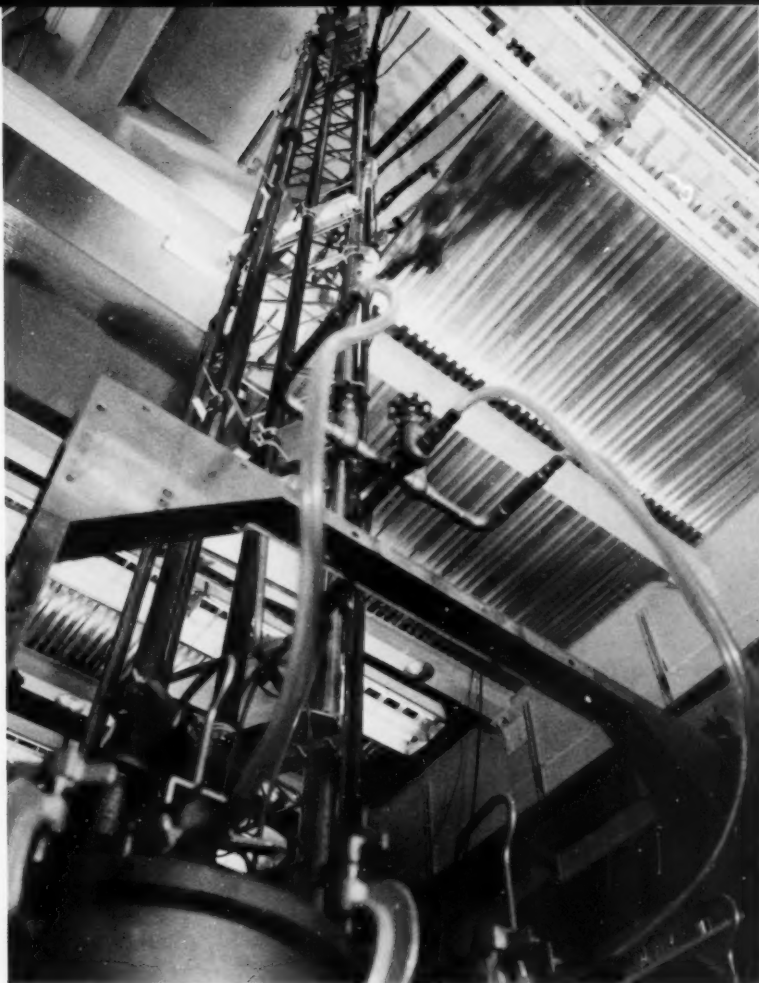
proved a new Federal regulation establishing a Federal program for standardizing data elements and representations used in government automated data systems and for the exchange of data among Federal agencies, State and local governments and the public.

NBS is assigned responsibilities for arranging for the development and publication of standards and for providing technical and administrative procedures to be used in the development, implementation and maintenance of standards. Also, NBS is responsible for maintaining selected registers of Federal standards and practices for assessing the impact of proposed and approved standards and for coordinating requests for exceptions and deferments to approved standards.

## Scientific Data Acquisition

To ease the communication between scientific experiments and computers or data-logging systems, an NBS experimental scientist, working with a digital electronics firm, has developed MIDAS, a user-oriented, modular digital interface system based on CAMAC hardware and USASCII-bus data communication. MIDAS modules enable the experimenter to set up, program, modify and operate automated or computer-controlled experiments independently of the experts.

Salient features of the concept and operating configurations are given in NBS Technical Note 790, MIDAS Modular Interactive Data Acquisition System—Description and Specification. The publication may be ordered as SD Catalog No. C13.46:790 from



*For generating pulsed waveforms of a known predicted shape, Standard Waveform Generator apparatus towers over one story high at NBS Boulder laboratories. Pressure vessels containing polar liquid sit on floor in foreground. Pressurized nitrogen gas entering vessels forces polar liquid into copper transmission line extending to top of tower.*

the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for 75 cents.

#### **Automation and Public Service**

NBS will sponsor a conference on Automation Technology Applied to Public Service on May 21-22, 1974. This conference, to be held on the NBS Gaithersburg campus, will provide an opportunity for users and developers of automation technology to obtain information needed to carry out their responsibilities in such areas as occupational safety and health, communications, aids to the handicapped, energy and transportation.

Automation technology now in existence or forecast for development in the near future can be adapted to satisfy many of the critical requirements of public service. Efficient channeling of automation technology development depends upon a clear understanding of the needs of organizations responsible for public service.

For information, write Edwin G. Johnsen, A130 Technology Building, NBS, Washington, D.C. 20234.

#### **Pulsed Waveforms**

Pulsed waveforms of a known predicted shape can be generated using a lossy uniform transmission line de-

veloped at NBS Boulder. When evaluating sampling oscilloscopes, it is often necessary to know the wave-shape of the input pulse to a high degree of accuracy. One way of doing this is to generate a transition or narrow pulse using an extremely fast device operating into a length of lossy uniform transmission line that is terminated in a 50- $\Omega$  load.

#### **Microwave Anechoic Chambers**

NBS has made a significant improvement in the method for evaluating microwave anechoic chambers through the development of a new isotropic probe and scanning mechanism for rapid, accurate evaluations of reflectivity levels in anechoic chambers. The probe is omnidirectional within  $\pm 1$  dB and has sufficient sensitivity to permit evaluation of reflectivity levels as low as  $-59$  dB. Complete scattering information is obtained from only three orthogonal scans per frequency.

#### **Selection of Flooring**

The selection of flooring with respect to service life, maintenance, obsolescence and trade-off advantages is discussed in NBS Technical Note 783, Durability and Maintenance as Related to the Selection of Flooring. Also considered are appearance, comfort and safety. Field observations and preliminary field tests conducted by NBS that indicate areas in which research is needed are included in this report.

Order from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, as SD Catalog No. C13.46:783 for 90 cents. □

**NBS PROBES IN DEPTH:  
SCIENTIFIC FLOODLIGHT  
AIMED AT**

# **DARK CORNERS OF CORROSION**

**T**O the average citizen, corrosion is a nuisance that puts a crimp in his wallet now and then when he has to peel off a few twenties to pay for replacing a hot water heater or tailpipe or roof gutter. Less visible are corrosion's effects on Uncle Sam's bankroll, from which an estimated \$15 billion or more is currently taken annually to pay for corrosion-wasted resources and related losses in industry and government.

And money is not the only thing. Corrosion is downright dangerous. It can fell bridges, sink ships, explode pipelines, cause airplane crashes and contribute—singlehandedly, or with accomplices—to an astonishing variety of casualty lists. Corrosion, aided and abetted by pollutants, ravages the Nation's monuments and art treasures. What is more, corrosion can be hazardous to your health by affecting nature's metabolism and, ultimately, your own.

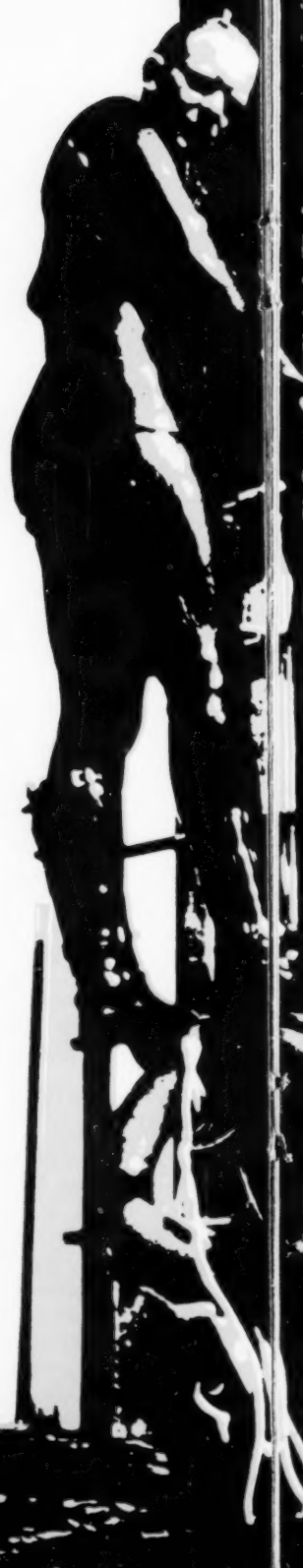
Everybody is against corrosion but few people feel they can do much about it besides pay the bills. Not so the skilled crew of corrosion fighters at the National Bureau of Standards. These experts in metallurgy and related disciplines, drawing on more than half a century of NBS experience in the complex corrosion field, provide a central resource for groups

of researchers in public and private laboratories around the world.

Corrosion is a now-you-see-it, now-you-don't kind of public enemy. Most people would not think of it, for example, in connection with the poisonous mercury compounds that threaten to invade the human food chain. But corrosion does seem to get into this picture and NBS scientists are working with the Environmental Protection Agency to find out just how. Indications are that the poison pathway may look something like this:

Microbes in soil and water convert mercury and its organic salts into unstable, highly toxic methylmercury. Vegetables, fish and shellfish may be exposed to contamination from this source. As staples of the human diet, these popular food items may in turn contaminate people.

Thus, a corrosive biochemical interaction—between microbes and mercury—is under scrutiny. The NBS investigating team is led by a microbiologist, who has long observed corrosion's microbial underworld, and a colleague in the Bureau's inorganic chemistry section. They are developing a workable method for chemically neutralizing or preventing the transformation of mercury into its poison-







*Making electrochemical measurements on a Chesapeake Bay core sample, Dr. Warren P. Iverson of NBS is shown aboard the Johns Hopkins University research vessel, the Ridgely Warfield, looking into the biochemical corrosive process by which mercury and other heavy metals are converted into poisons that may enter the human food chain.*

ous forms. Such a method could be applied also to the threat of poisoning from other heavy metals such as cadmium, lead, tin and arsenic.

Close attention must be given to corrosion economics as well as to corrosion science. When the Rural Electrification Administration found itself confronted with uncertain supplies and rising prices of copper, it enlisted NBS help in finding substitute shielding materials for buried telephone cables going into service throughout the country.

From Cape May clay to Hagerstown loam, NBS experts have been experimenting in various soils with scores of shielding materials. Telephone cables are not alone in needing such protection. Also to be considered are building foundations, bridges, breakwaters, tanks, towers, piers, docks and heavy industrial installations. Corrosion research is aimed at protecting all such structures.

With the American Iron and Steel Institute and U.S. Army coastal engineers, the Bureau's corrosion fighters have been experimenting at a Navy site on the Virginia coast since 1967 to see how nearly 100 steel pilings jettied 5.7 m (19 ft) into the sand will fare under various systems of protection against wind, wave, salt

*turn page*

## CORROSION *continued*

spray and microorganisms. One piling from each of 31 different sets is being pulled at 5-year intervals and a whole series of sensitive analyses is being performed on each.

Some of the pilings in the experiment are made of carbon steel, others of low-alloy steel. Some are protected with coatings such as coal-tar epoxy, galvanizing, aluminum and zinc flame spray and zinc-rich paints, while certain pilings have cathodic protection featuring "sacrificial" metals introduced into the assembly to corrode in place of the structural steel. The materials and techniques will be compared over a 15-year period of exposure to water, sand, tides, wind and salt spray.

### Surgical Implants

Even when the research locale shifts far inland, there is a connection between marine corrosion and some other materials problems. Medical researchers point out that plasma or body fluid resembles warm, aerated seawater.

As might be expected, experience confirms that bone fracture pins, surgical implants, dental fillings and artificial limbs and organs are subject to crevice corrosion and pitting and galvanic corrosion. Some of the important research aimed at resolving this problem is taking place at NBS. Part of the effort centers on titanium, a metal noted for high resistance to corrosion and physiological salt solutions. The Bureau's metallurgical specialists are observing titanium's behavior in simulated body fluids containing uric and amino acid. Using electron microscopy and electrochemical techniques, these scientists are studying surface reactions, surface films and the microstructures of titanium and other metals and alloys that may prove superior in standing up to the body's corrosive internal atmosphere.

Corrosion fighting is likewise an essential ingredient of mankind's struggle to keep from running out of

water. Desalting plants use vast amounts of metal tubing that must function in hot, rapidly moving sea water—just about the most corrosive environment there is. Severe corrosion constantly threatens desalting plant components such as trash grates; travelling screens; pumps, valves and pipes for conducting raw, chemically treated sea water and distilled water; exchanger tubes and tube sheets; vessels and structural members. In the recent past, for the



*Corrosion tubercles visible on the inside wall of this steel pipe resulted from a corrosive, bacterially-induced sulfate reducing process, according to Dr. Warren P. Iverson, NBS microbiologist. The blame in this case fell on a species known as *Desulfovibrio desulfuricans*.*

Department of Interior's Office of Saline Water, NBS has conducted a series of basic corrosion studies.

It is often hard to distinguish the Bureau's corrosion research from its failure analysis, and vice versa. The two are twin NBS concerns and are closely interrelated. Corrosion may be the prelude to accident or catastrophe, and authorities must weigh its role as they sift through the evidence.

Often it is found that what the layman loosely calls a "crack-up" is exactly that. Stress corrosion cracking can lay a battleship low, wreck a tank truck or ruin your lawn mower. This particularly destructive form of corrosion is receiving the close attention of NBS researchers who are developing new insights into its nature and new tools for dealing with it. The latest of these is a technique known

as tribo-ellipsometry, devised as an aid in predicting an alloy's performance against stress corrosion cracking.

Tribo-ellipsometry is a tool which may contribute to improving industrial management's gift of prophecy. Metals in service form an oxide film—a product of mild corrosion that, reaching a passive state, serves to protect the metal against further corrosion if the film is not itself destroyed. Ruptures in the film are followed by renewed film formation, with some loss of metal; too many or too severe breaks can mean relentless corrosion, formation of cracks and eventual failure. With tribo-ellipsometry in its tool kit, NBS is now able to simulate film rupture by abrading off the oxide film, rapidly measuring film regrowth and estimating the amount of electrical current consumed by metal dissolution as distinguished from current used in film growth. From such data it becomes possible to derive clues that will aid in the forecasting of a metal's future in various environments and corrosive atmospheres. The new technique contributes to better understanding of stress corrosion's basic mechanism.

### Corrosion Rollback

Thoughts of a corrosion cure-all can probably be left to the confirmed optimist, but it is indisputable that corrosion can be rolled back and often warded off by the use of improved materials and design and preventive maintenance. Industry statisticians talk of the "average useful life" of steel; for example, in 1920 it was about 23 years, by 1940 it had risen to about 35 and today the trend is still up, in spite of a variety of "severe" environments that metals face under modern conditions of use.

President Nixon's National Commission on Materials Policy has gathered data indicating that at least \$5 billion of the estimated \$15 billion annual U.S. corrosion loss is recoverable through already available corrosion control techniques. □

**A** series of tests conducted by the National Bureau of Standards indicates that perhaps half of the estimated 500 yearly single-fatality deaths due to fire in nursing homes could be prevented if these facilities were equipped with smoke detector-activated sprinkler systems.

This is the estimate of Richard L. Custer, project leader for suppression systems with the Fire Technology Division of NBS. Unfortunately, very few of the homes for the aged in the United States have any kind of sprinkler system.

The U.S. House of Representatives Committee on Government Operations, when hearing testimony on nursing home fires, asked NBS to determine if better protection could be provided with currently available products. Subsequent Bureau tests on smoke, carbon monoxide (CO) and temperatures experienced during the fires, and the reaction times of various systems, attempt to address only a part of the problem of all fire deaths in nursing homes.

### Smoldering and Open-Flame Tests

All NBS tests were conducted in a room measuring 3-m square (10 ft) by 2.7-m (9 ft) high. Two sheets on a single bed set with its head elevated and against one wall simulated a small nursing-home room. A ceiling sprinkler was placed directly over the foot of the bed beside the detector. Temperatures were measured with thermocouples placed at the ignition point, the bend in the mattress and at the head.

Reaction times of both conventional and smoke detector-activated sprinklers were compared in high-energy, open-flame and low-energy, smoldering fires. To produce a smoldering fire, a cigaret was placed between the sheets. The smoke detector-sprinkler system extinguished the fire after about 25 minutes when only an 11.1-cm (5-in) diameter charred area had been made. If a nursing-home resident caught in this kind of fire

## NURSING HOMES

### ... AND A FIRE "CONNECTION"



*The smoke detector-activated sprinkler system limited damage to a smoldering bed to a small patch. Readings from thermocouple wires indicate that temperatures outside the burned area did not rise to a dangerous level.*

had not been in contact with the 500 °C (900 °F) smoldering spot, he would not have been burned. A sprinkler by itself probably would not react until a large portion of a bed had been consumed, and the CO concentration would almost surely become lethal for an elderly person, Custer stated.

In the test of an open-flame, high-energy fire, a cigaret lighter was dropped onto the sheets. Where the fastest commercially available sprinkler did not respond until almost 3 minutes had passed, only 30-40 seconds would be needed before the smoke detector would react to put out the rapidly growing blaze. In both cases there was an open flame at the point of ignition. With a sprinkler system only, the mattress temperatures at the head of the bed exceeded 800 °C (1500 °F).

Had the combination smoke detector-sprinkler system been used the crucial head-of-the-bed temperature would have remained below 38 °C

(100 °F). In a room protected in this fashion, residents would not be exposed to breathing high-temperature vapors such as those experienced by a person trapped in a flaming bed. Before a conventional system would respond such a person would suffer seriously burned lungs, trachea, throat and mouth linings.

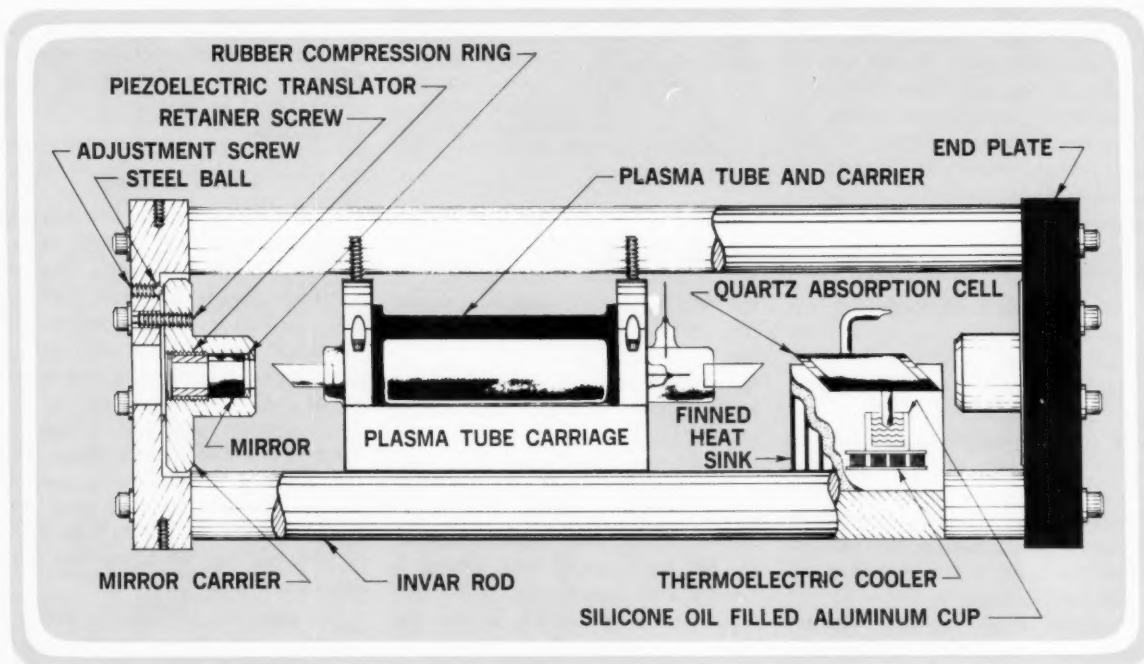
A sleeping nursing-home resident suffering this head-of-the-bed temperature could not survive long even if the lethal CO was not present. Although the ignition point would reach very high temperatures in either case, the difference in reaction time of the sprinklers (nearly 3 minutes compared to 30 seconds) is perhaps the most crucial element in the comparison. It could determine whether sleepwear catches fire. With the operation of either sprinkler system, however, water application can drop temperatures to safe levels within a few seconds.

### High Price Tag

One reason why so few nursing homes have sprinkler systems is the cost. To install smoke detector-activated models may cost \$400 to \$800 per bed in existing centers and about half that when installed during construction. The primary cost is not in the individual components of the smoke detector-sprinkler system as much as in the special plumbing, wiring and control box devices needed. The heat-sensing sprinkler most people are familiar with costs from \$100 to \$200 per bed when installed during construction.

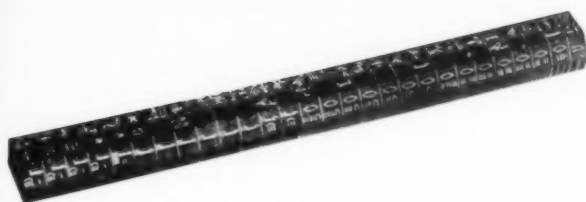
The price tag of \$800 per bed for alteration with the new system can be considerable for a large nursing home with over 200 residents. This kind of a smoke detector-sprinkler system was developed privately 3 years ago. If the demand for the added protection becomes great and the volume of production increases, the prices could conceivably come down. Regardless of cost, the benefits are considerable. □

# TOWARD A NEW STANDARD OF LENGTH



*Cutaway view of iodine-stabilized laser studied at NBS. A feedback arrangement continuously adjusted the mirror position (via the piezoelectric translator) to lock the laser wavelength to an absorption line of iodine-129 gas contained in the quartz absorption cell.*





*An ancient length standard, the royal cubit of Egypt (around 1550 B.C.), made of black granite. The cubit, which means "forearm," was subdivided into two spans, six palms, and 24 digits or finger breadths.*

*The present definition of the meter, adopted in 1960, is in terms of the wavelength of the orange radiation from a krypton-86 lamp. As shown here, the lamp is enclosed in a liquid nitrogen bath, the radiation emerging from the opening at the lower right.*

If they wanted to, scientists could now replace the existing 13-year-old standard of length (a specified number of wavelengths of the orange radiation from krypton-86) by a much more accurate one based on advanced laser technology.

They are not expected to do so, however, for a few years, since the change can be made in different ways and it is not yet clear which is best. Also, each of the alternatives would have more or less serious and temporary inconveniences for some of the scientists—astronomers, geodesists, metrologists, physicists—working at the highest levels of accuracy in the measurement of length.

An important first step toward a change in the standard was taken in a report made in October 1973 by the Consultative Committee for the Definition of the Meter (CCDM) to the International Committee of Weights and Measures. In that report the CCDM recommended adoption of specified 9-digit values for the wavelengths generated by two molecular-absorption-stabilized lasers and for the speed of light. And from the discussions accompanying the report it seems likely that the way is being prepared for a redefinition.

The efforts to improve the standard of length, which were under way al-

most as soon as the present definition was adopted in 1960, are a good example of the elaborate and painstaking investigations, cross-checked by laboratories around the world and combined with advanced theory and ingenious experimental procedures, that are characteristic of modern science.

### The Path to the Present

To see where these efforts have brought us, it will help to look briefly at earlier standards.

The French scientists who framed the original definition of the meter in 1791 seemed to be obsessed by the idea of indestructibility. They felt that a metal rod, as previously used, was too easily damaged to serve as the primary standard. So they chose, instead, the earth itself, defining the meter as 1 ten-millionth of the distance from the north pole to the equator along the meridian through Dunkirk.

A large-scale project was undertaken to measure the quarter meridian and the result was embodied in a metal rod to represent 1 ten-millionth of it. In principle, the length of the rod could be rechecked by another such project, but this was so difficult that a metal rod served for

decades as the effective standard. More recent earth measurements have shown that the original measurement of the quarter meridian was in error by 1 part in 5,000.

In 1875, the metric convention, signed by the United States and 17 other countries, adopted as the primary length standard a bar of platinum-iridium, on which were inscribed two lines whose spacing defined the meter. This spacing maintained as nearly as possible the size of the meter then in use. The limiting uncertainty inherent in this standard was believed to be about 1 part in 10 million.

The possibility of an entirely different type of length standard, a wavelength of light, had been suggested as far back as 1827 by the French physicist Babinet. Nothing came of the suggestion until the end of the century when Michelson began making measurements with the interferometer that bears his name. With the interferometer, Michelson could accurately compare light wavelengths with ordinary lengths like measuring rods. He also had available a light beam, the red light from cadmium, that was both sufficiently intense and sufficiently monochromatic for the purpose.

*turn page*

## LENGTH *continued*

A perfectly monochromatic source, one that radiates a single isolated frequency, and therefore a single wavelength, is a theoretical abstraction and not producible in practice. Every actual source radiates over a range of wavelengths, and the narrower this range—i.e., the narrower the spectral line—the more accurate a length standard it can provide.

By 1905, spectroscopists and atomic physicists were using the cadmium radiation as a standard for high-accuracy wavelength comparisons. It was not, however, until 1960 that the platinum-iridium bar was replaced by a wavelength standard for the scientific community as a whole.

This was adopted by the Eleventh General Conference of Weights and Measures, which defined the meter as 1,650,763.73 wavelengths in vacuum of the orange radiation emitted by isolated atoms of krypton-86. The Conference further specified how a krypton lamp was to be constructed and operated in order to provide this same wavelength. Experience has shown that any two krypton lamps, properly constructed and used, will agree within 4 parts in a billion.

Primarily responsible for this high degree of reproducibility was the development of methods for separating pure isotopes, like krypton-86, which radiate particularly narrow spectral lines.

### Lasers and Length

The same year, 1960, also saw the development of the first gas lasers, which could continuously generate radiation with a much narrower line width. The trouble was that the wavelength of the radiation tended to change because it depended on the dimensions of the laser cavity and other characteristics difficult to hold constant. For the same reason, one could not expect two different lasers, though built to the same specifications, to have the same wavelength.

A solution came in 1967 with the

idea of "saturated absorption." This enables one to "lock" the laser wavelength to the absorption line of a gas. A gas that can generate a narrow spectral line also absorbs radiation only if it falls within the wavelength range of that same spectral line.

In a laser stabilized by saturated absorption, a transparent cell containing a gas, such as methane, is placed inside the laser cavity. The intensity of the laser beam will then depend on how closely its wavelength matches that of the gas absorption line. A feedback mechanism can be designed to take advantage of this, continually varying, say, the position of one of the laser end mirrors so as to prevent the wavelength from departing more than a very small amount from the maximum absorption wavelength of the gas.

Among the stabilized lasers most studied thus far are those mentioned in the CCDM recommendations: helium-neon lasers stabilized by methane or iodine. The most recent experiments at NBS, dealing with helium-neon lasers stabilized to absorption lines of iodine-129, were carried out by W. G. Schweitzer, Jr., E. G. Kessler, Jr., R. D. Deslattes, H. P. Layer and J. R. Whetstone. At the present stage it is believed possible to design stabilized lasers of these kinds that are reproducible to 1 part in 10 billion, with a good chance of attaining 1 part in 100 billion. To illustrate their stability, NBS scientists have built methane-stabilized lasers whose frequency, averaged over successive 10-second intervals, varies by less than 1 part in 10,000 billion (1 part in  $10^{13}$ ).

### Why the Speed of Light?

Not only does the wavelength of a certain radiation serve as the standard of length, but the frequency of another radiation (emitted by cesium) is used in defining the second of time.

But what if the same radiation were used for defining both the second and the meter? These definitions

would then automatically determine the value of the speed of light. This would be the case because, for any kind of waves, speed equals frequency times wavelength.

In fact, it is now feasible to use any of the radiations mentioned as a basis for both time and length standards, although for various reasons this is not considered practical.

On the other hand, if we assign, by convention, a value to the speed of light (which, in vacuum, is the same for all electromagnetic radiations), then that value together with a radiation-based definition of the second, would fix the unit of length. That is, the meter would be the distance the radiation travels in a specifiable time. Or, the assigned speed of light, together with a wavelength definition of the meter, would fix the length of the second: namely, as the time needed for light to travel a specifiable distance.

What gives these considerations interest is that it recently became possible to make direct measurements of the speed of light with an accuracy comparable to those of the definitions of the meter and the second.

Underlying the increased accuracy of the speed of light are new techniques, pioneered by Javan and co-workers at MIT, for generating exact multiples of a given frequency. This makes it possible to measure a laser frequency (of the order of  $10^{14}$  hertz) by comparing it with some multiple of a lower frequency; then comparing the latter in the same way with a still smaller frequency; and so on for several steps until an accurately known frequency, usually in the microwave range, is reached.

This method was further developed by scientists of the NBS Boulder laboratories, Kenneth M. Evenson, Joseph S. Wells, F. Russell Petersen, Bruce L. Danielson and Gordon W. Day, who succeeded in 1972 in measuring the frequency of a methane-stabilized laser to 6 parts in  $10^{10}$ .

This result was combined with a careful measurement of the wave-

RECOMMENDATIONS OF THE CONSULTATIVE  
COMMITTEE FOR THE DEFINITION OF THE METER

1. that the value  $3\,392\,231.40 \times 10^{-12}\text{m}$  be used for the wavelength emitted by a helium-neon laser stabilized to the P(7) line in the  $\nu_3$  band of the methane molecule.
2. that the value  $632\,991.339 \times 10^{-12}\text{m}$  be used for the wavelength emitted by a helium-neon laser stabilized to the "i" component of the R(127) line in the 11-5 band of iodine-127.
3. that other lines in the iodine molecular spectrum could also be used as length standards, and that since they could be related to the "i" component by difference-frequency measurements, their calculated wavelengths would therefore be of the same accuracy as the "i" component. As an example, the wavelength of the "B" component of the iodine-129 molecule is given as  $632\,990.078 \times 10^{-12}\text{m}$ .
4. that the value  $299\,792\,458\text{ m/s}$  be used for the speed of light.

The uncertainty assigned to all the above values is 4 parts in  $10^9$  which is the uncertainty associated with the present (krypton-86) definition of the meter, in terms of which the values are expressed.



Meter Bar 27, the U.S. national standard of length from 1893 to 1960, one of a number of copies of the platinum-iridium prototype meter maintained by the International Bureau of Weights and Measures in Severs, France.

length of the same laser, on the basis of the krypton standard, made by Richard L. Barger and John L. Hall, also of NBS. Multiplying the measured frequency and wavelength gave a value for the speed of light accurate to 4 parts in  $10^9$ . This value, which is consistent with other recent determinations, is the one recommended by the CCDM.

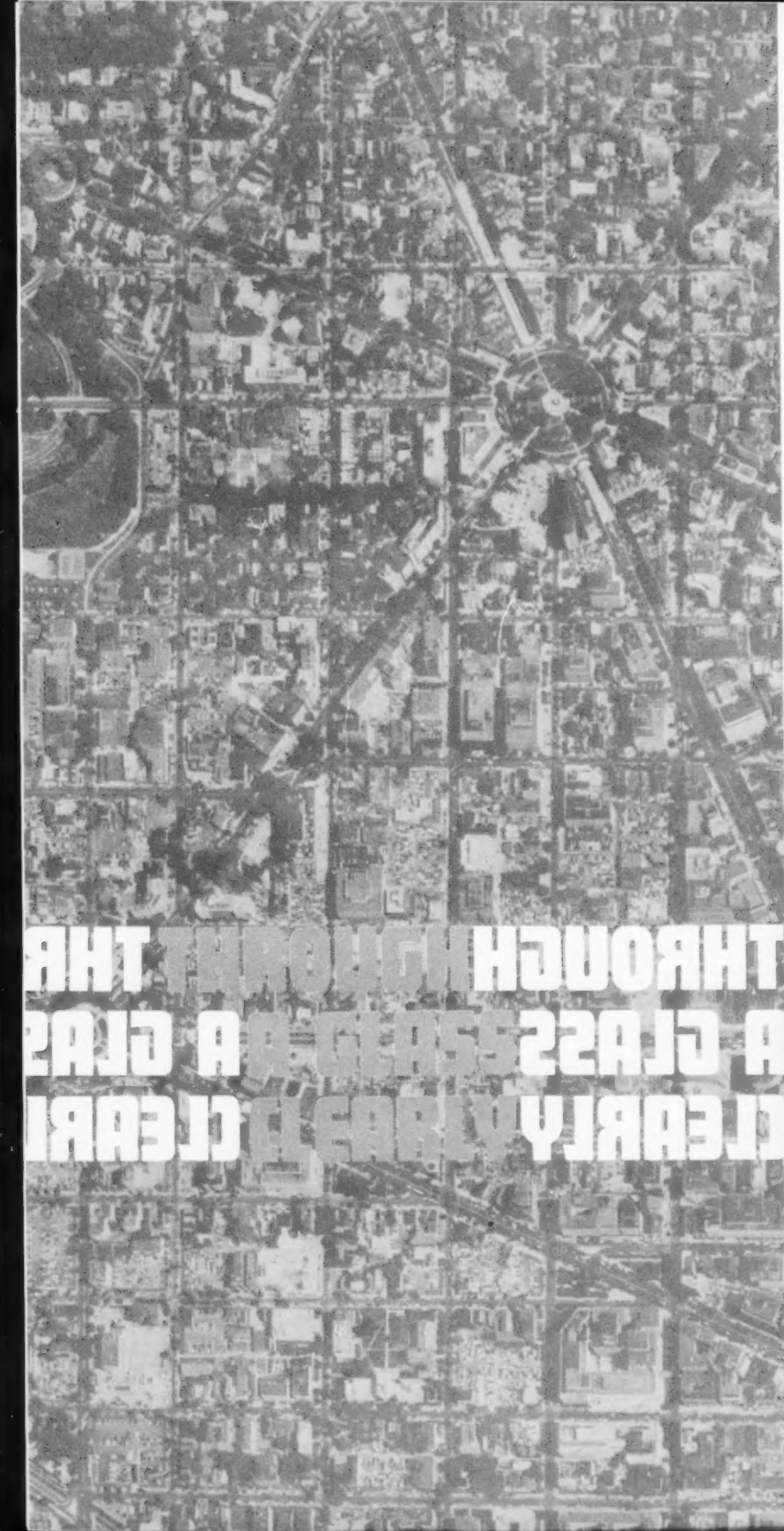
#### Alternatives

In view of the advances in stabilized lasers, in laser frequency measurements and in the determination of the speed of light, it is now clearly possible to redefine the meter so that it can be more accurately reproduced in the laboratory. One possibility is to redefine the meter in terms of the wavelength of one of the stabilized lasers. The other is to take as the meter the distance traveled by electromagnetic waves in vacuum during a specified fraction of a second, the fraction being the reciprocal of the value adopted for the speed of light.

The two alternatives correspond, respectively, to current practices of physicists and engineers for high-accuracy measurements of shorter distances and to such measurement of longer distances by astronomers and geodesists. Physicists generally rely on wavelength counts made with the help of an interferometer. Astronomers, on the other hand, make direct use of the speed of light, using radar techniques to measure the time it takes a light pulse to travel between the end points of the distance being measured. The travel time times the speed of light gives the distance. In this way, using the latest value for the speed of light, NBS scientists recently determined the distance to the moon with an accuracy of a few parts in  $10^{10}$ .

The CCDM report expressed the hope that, whichever type of redefinition is finally adopted, it would be so formulated that the associated value of the speed of light would be the same as the one recommended in the report. □





**F**EW objects have had so significant and continuing an impact on science and everyday living as those modest-appearing bits of smooth and rounded glass we call lenses. The first important use was for eyeglasses, probably in the 13th century. More spectacular applications did not occur until the 17th century with the invention of the telescope and microscope.

Since then, lenses have become indispensable parts of thousands of specialized scientific instruments and consumer items ranging from the sportsman's binoculars to the slide projector and zoom-lens camera. These devices are invaluable tools in medicine and biology, the physical and behavioral sciences, satellite weather and earth resource surveys, the manufacture of integrated electronic circuitry, law enforcement and, of course, in the information and entertainment worlds.

The lens is not, however, as simple as it looks. Before it could do all the things we now expect of it, a long development of the art of making

# THROUGH A GLASS CLEARLY

*Downtown Washington, D.C., photographed from several miles up. White House is at lower right; the large hub is Dupont Circle. Precision camera lenses, such as the one used here, are among those calibrated by NBS.*

*DIMENSIONS / NBS*



optical glass and of our understanding of optical theory had to take place.

Furthermore, even slight errors in shaping a lens can cause twisting of lines, fuzziness from failure to bring light of different colors to the same focus or a spurious distribution of light intensity, any of which could impair the usefulness of a supposedly high-quality lens. To illustrate this problem, one need only consider the effects on measurements of photos from an aircraft high in the stratosphere, the monitoring of microelectronic circuits for computers and densitometry measurements of atomic and molecular spectra.

Hence the importance of developing suitable and sensitive tests of lens performance. At NBS, where much of this work has gone on, the latest step is the design of a device that rapidly and efficiently gives the wide range of information about lens characteristics needed.

### Characterizing a Lens

For a long time, lens testing concentrated on determining "resolving power." This, roughly speaking, gives the size of the smallest detail that can be distinguished in the image formed by the lens.

More recent optical theory, exploiting the mathematician's Fourier transform and autocorrelation functions, broadened the lens-test concept to include measurement of the optical transfer function (OTF), a mathematical characterization of the lens' ability to form an image. However, it is now known that a more fundamental characterization of lens performance is given by the pupil function, from which we can calculate the OTF and the aberration coefficients that express the amounts of the different kinds of image distortion present.

The new NBS test device looks like a small cube of glass about 1 cm (half an inch) along an edge and is called a wavefront shearing interferometer. It is designed primarily to measure the pupil function. Besides containing the information needed for determining the OTF and the aberration

coefficients, the pupil function has two other advantages: it can be used to evaluate (1) complex optical systems composed of several lenses that have been individually tested and (2) optical systems employing either coherent illumination, as from lasers, or partially coherent illumination, as from incandescent lamps.

The Wavefront Shearing Interferometer (WSI) is essentially a compact cubical form of a Michelson interferometer, typically 1 cm on a side, formed by cementing together two 45°-90°-45° quartz prisms along their hypotenuses. One hypotenuse is coated with aluminum to partially transmit and reflect light, and is rotated slightly (a tenth of a degree or so) with respect to the other before allowing the cement to set. One other face of each prism is coated to reflect all light internally in the cube.

Unlike most other interferometers, the WSI has no need of a reference beam or of a mirror with known surface properties. It is also relatively insensitive to vibration and thermal

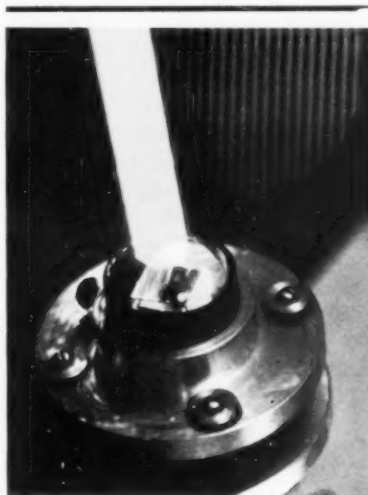
effects and is easy to use, with a comparatively short time required for data acquisition. Lastly, it is portable and inexpensive to manufacture and install.

In testing, a light beam passing through the lens is divided by the WSI cube into two beams of equal intensity which are sheared (displaced sidewise) with respect to each other. The two beams emerge from the cube and where they overlap an interference pattern of alternate light and dark fringes occurs. The fringe pattern is photographed and the negative scanned by a microdensitometer to measure the fringe locations. The fringe data are fed into a computer which then calculates the pupil function, aberration coefficients and the optical transfer function.

Besides testing lenses, the WSI can be used to test mirror systems. The cube was placed at the focus of a 1-meter-diameter telescope mirror in an astronomical observatory to determine performance during typical viewing conditions. Another WSI is being assembled to test parabolic mirrors to be used in a laser-fusion investigation of ways to provide useful energy from controlled nuclear fusion.

### NBS Lens Calibration Service

A lens calibration and test service using the WSI is presently offered by NBS. It is described in *Calibration and Test Services of the National Bureau of Standards*, NBS Special Publication 250, available prepaid at \$2.00 each from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Further details on the calibration service can be obtained from John M. Jerke, National Bureau of Standards, Bldg. 220 Rm. A123, Washington, D.C. 20234; telephone 301/921-2185. Technical details on the WSI are given in "Lens Testing with a Simple Wavefront Shearing Interferometer" by D. Nyyssonen and J. M. Jerke, *Applied Optics*, 12, 2061 (Sept. 1973). □



*The cube-shaped wavefront-shearing interferometer is seen here near the center of the photo. The light beam comes from a lens under test (not shown) and enters the cube, which splits it into two overlapping beams. These beams emerge towards the rear and form an interference pattern (light and dark stripes) on a screen.*

# AT THE SIGNAL ...VIA SATELLITE TIME

A successful 2-year experiment in broadcasting time and standard frequency signals from an earth satellite has been completed by the National Bureau of Standards.

Radiated downward from the National Aeronautics and Space Administration's ATS-3 satellite, the signals came in strong and stable. They blanketed the North and South American continents, much of the Atlantic and Pacific oceans and part of Europe and Africa, for a total of 40 percent of the earth's surface.

Satellite-relayed signals have high signal-to-noise ratios, wide bandwidth (permitting flexibility in signal input) and line-of-sight propagation paths free from fading. Signals with these characteristics are especially helpful in regulating and monitoring electric power, recording times of earthquakes and other events, monitoring automobile and airplane traffic, controlling timing of digital communications systems and performing other significant functions.

## New Horizons

In the future, a satellite system based on this experiment may offer continuous time and frequency broadcasts as dependable as the local AM or FM radio station, covering a large global area with a timing accuracy better than one one-hundred-thousandth of a second.

Such a service would supplement the NBS time and frequency stations, WWV and WWVH, which are limited by noise and propagation path variations, and normally cover only 10 to 15 percent of the earth with equal reliability.

In the experiment, a frequency-

modulated 149-MHz (million cycles per second) carrier wave was transmitted for two 15-minute periods a day from the NBS Boulder, Colo., laboratories to the satellite, which then rebroadcast the signal back to earth on a 135-MHz carrier.

The satellite was given the speed needed to make one complete revolution in just 24 hours, which kept it poised 36 kilometers (22.4 miles) over a fixed point on the equator at about 70 degrees west longitude.

## Global Outposts

Four NBS-equipped receiving stations, widely distributed around the point directly below the satellite, determined that these satellite disseminated signals had better than a 25-microsecond timing accuracy. The stations were located at NBS Boulder and Air Force Cambridge Research Laboratory, Mass., in North America; and at the Smithsonian Astrophysical Observatories at Arequipa, Peru and Natal, Brazil.

During the experiment conducted by D. Wayne Hanson, Wallace F. Hamilton and Alvin J. D. Clements of the NBS Time and Frequency Division, the satellite-relayed signals were based upon the NBS Frequency Standard and NBS Coordinated Universal Time, both maintained at the Boulder NBS Laboratories.<sup>1</sup> A standard frequency 1-kHz tone, second ticks, voice announcement of the time of day and satellite position and a time

*Time signals are sent to the satellite from this helical antenna located at NBS/Boulder.*



code were relayed to the earth twice a day for 15-minute periods. The bandwidth for these signals was 30 kHz. Time recovery required simple techniques and simple path delay computations. Frequency was derived from audio frequency modulations or from time synchronization over a period of days.

Accurate time recovery depended primarily upon accurate satellite-position information. A 300-meter path error, for instance, represented a 1-microsecond timing error. ATS-3, a geostationary satellite, maintained a relatively fixed position in the sky because it rotated synchronously around the earth. However, the satellite deviated from a perfect 24-hour circular equatorial orbit. By occasionally firing rockets on the satellite, scientists prevented the satellite from drifting too far from the desired location.

Charts prepared by NBS for users of the satellite-time dissemination service gave receiver-antenna pointing information and propagation-path time delays. The delay charts showed about one-fourth-second delay between the master clock and the user via the satellite, and were accurate to a few milliseconds.

Most users employed a simple antenna and inexpensive receiver for recognizable voice and second ticks reception. High-accuracy users needed a high-gain antenna and a receiver of high-sensitivity and selectivity. Accessory equipment was also needed to synchronize local time and frequency to satellite relayed signals.

Anticipating future needs, the Space Telecommunications World Administration Radio Conference at Geneva in June 1971 allocated a  $400.1 \pm 0.05$ -MHz channel for satellite-to-earth time and frequency broadcasts. Additional experiments are needed for improving orbit determination, frequency dissemination and signal format. □

<sup>1</sup> Hanson, D. W. and Hamilton, W. F., Time and Frequency Broadcast Experiments from ATS-3 Satellite, NBS Tech. Note 645 in press.

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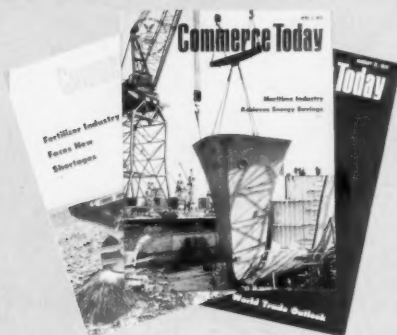
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